The CO Power Spectrum Survey:
"Don't stop thinking about tomorrow..."

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arXiv: 1605.03971 (Keating et al., 2016)

Pilot Studies in Intensity Mapping

SZA Dishes

The CO Power Spectrum Survey (COPSS)

1 cm intensity mapping experiment looking for CO(1-0), using archival SZ-targeted data and one year of new observations.

COPSS Collaborators:

Karto Keating (PI; CfA/SAO)

Geoff Bower (ASIAA)
John Carlstrom (Chicago)
Tzu-Ching Chang (ASIAA)
Dave Deboer (Berkeley)
Chris Greer (Arizona)
Carl Heiles (Berkeley)
James Lamb (CalTech)

Erik Leitch (Chicago)
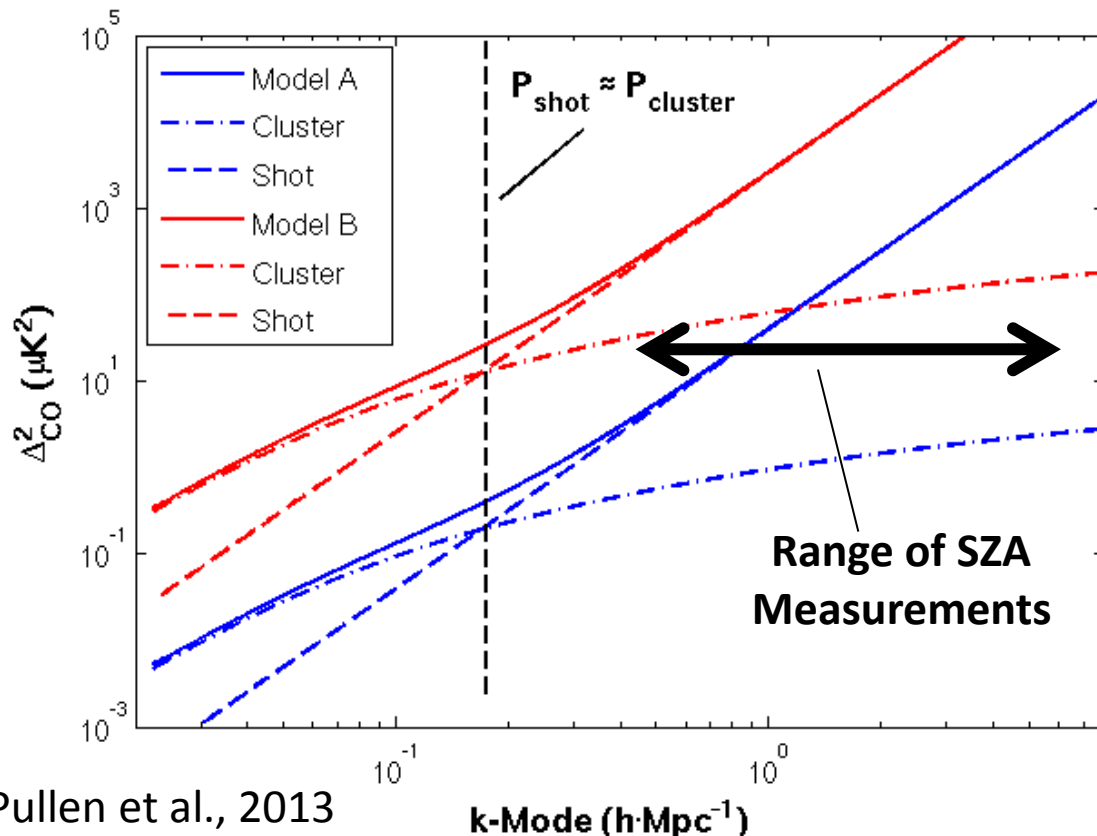**Dan Marrone (Arizona)**
Amber Miller (Columbia)
Stephan Muchovej (CalTech)
Dick Plambeck (Berkeley)
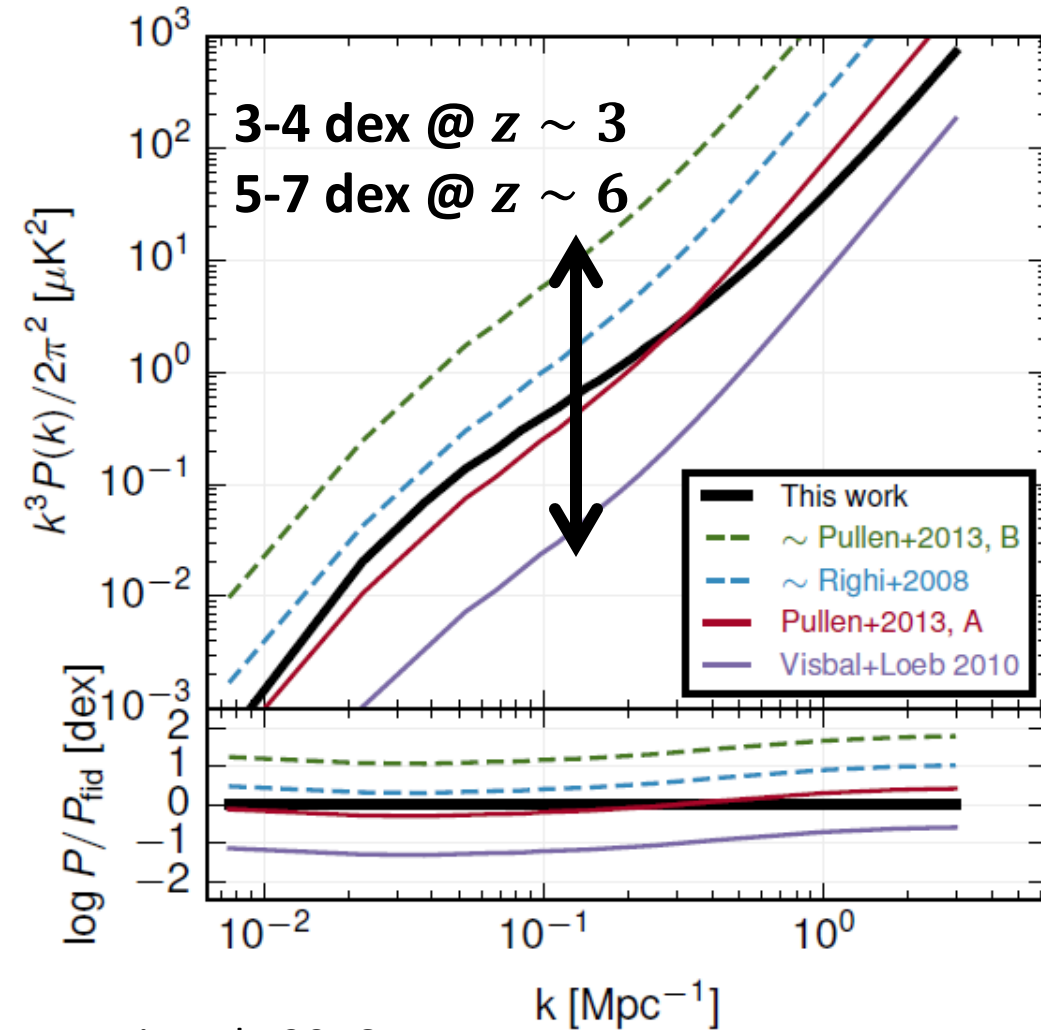David Woody (CalTech)

A Tale of Two Regimes

Pullen et al., 2013

Clustering Power: More cosmologically interesting, but difficult to access with existing instruments.

Shot Power: Can probe with existing instruments, but science case is more limited.

The Power of the Shot

3-4 dex @ $z \sim 3$
5-7 dex @ $z \sim 6$

Legend:
- **This work**
- $\sim$ Pullen+2013, B
- $\sim$ Righi+2008
- Pullen+2013, A
- Visbal+Loeb 2010

Li et al., 2016

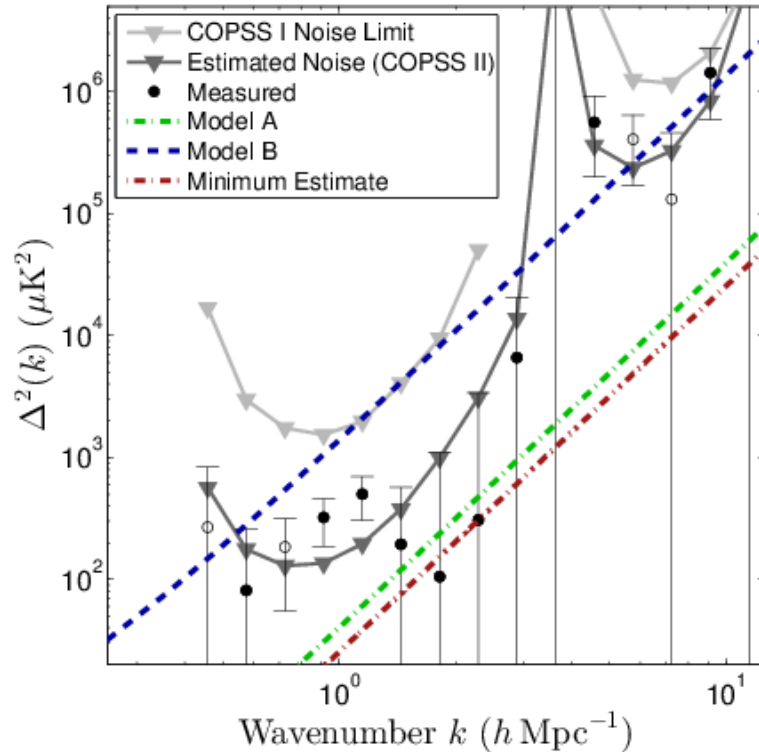*"Why target the poisson-dominated portion of the power spectrum?"*

Shot-power measurement could significantly constrain the large range of predictions for CO at z > 1, which make it difficult to justify/design a new instrument for.

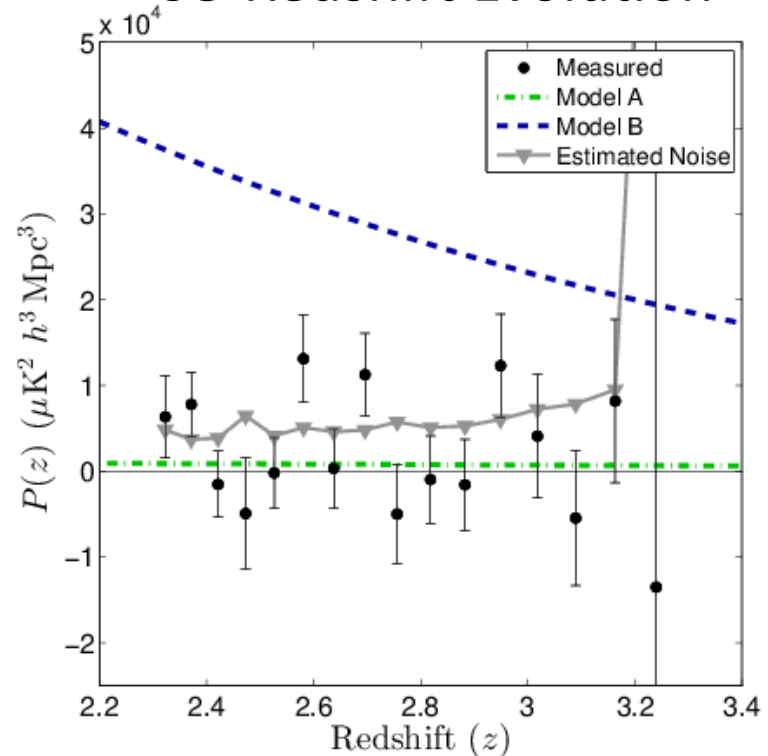**We saw COPSS as an important stepping-stone towards future instruments**

Primary Survey Results
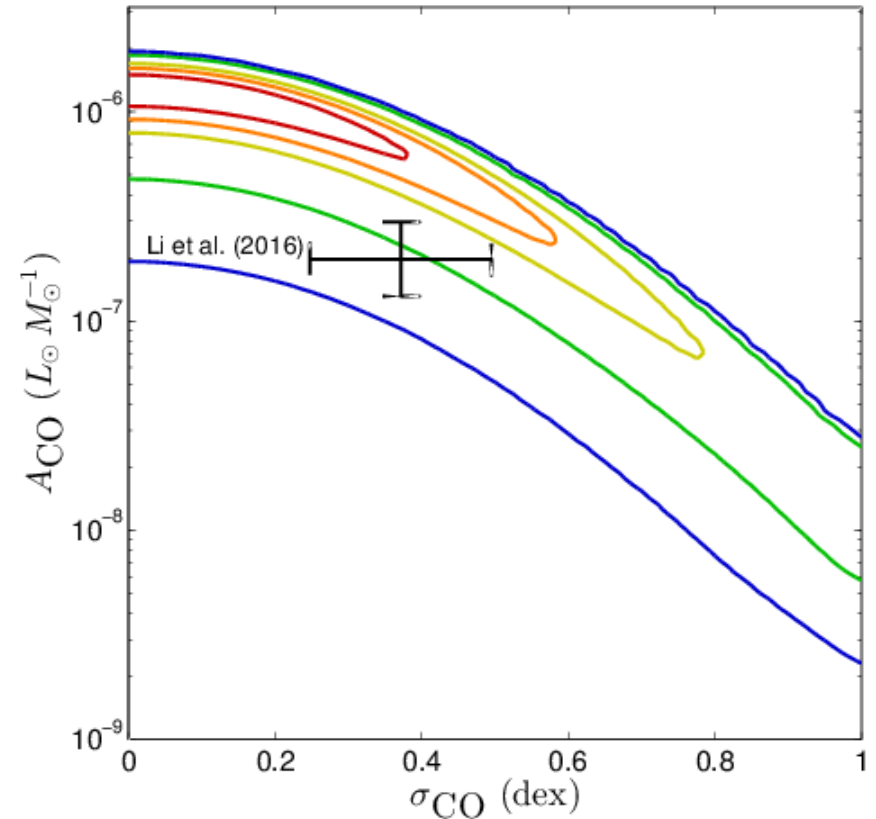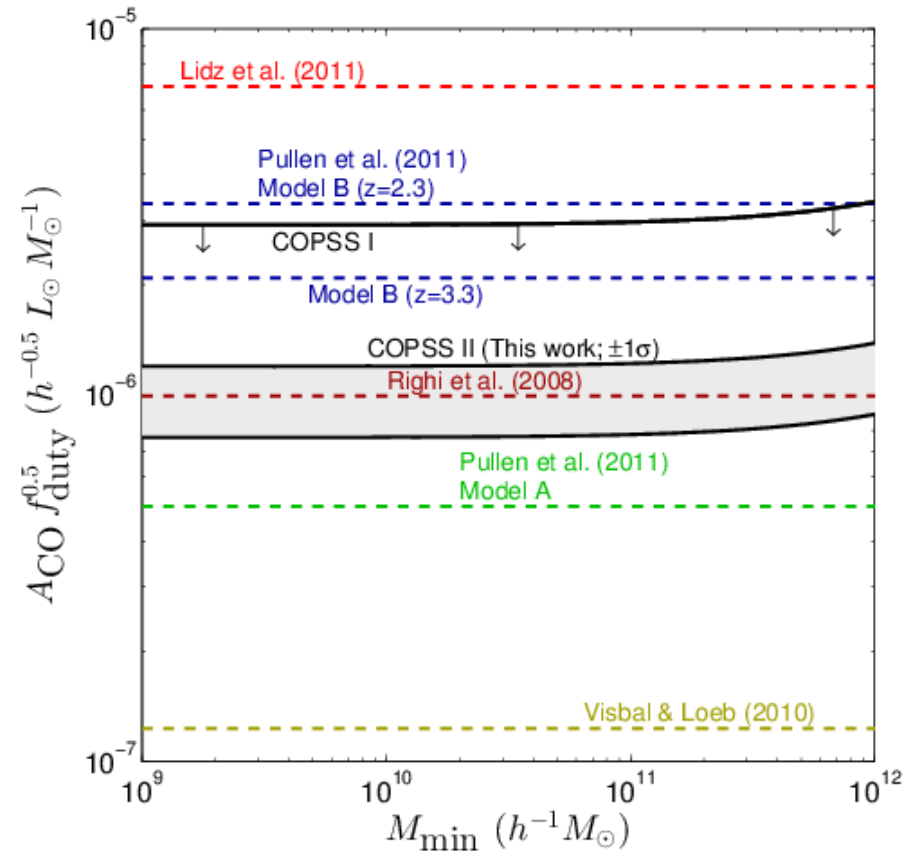
CO Power Spectrum

CO Redshift Evolution

Power spectrum for CO constrained to $P_{\mathrm{CO}} = 3.0^{+1.3}_{-1.3} \times 10^3 \; \mu\mathrm{K}^2 \; (\mathrm{Mpc}/h)^3$, $P_{\mathrm{CO}} > 0$ to 98.9% confidence. Weak evidence ($\sim 1\sigma$) of increasing power with decreasing redshift.
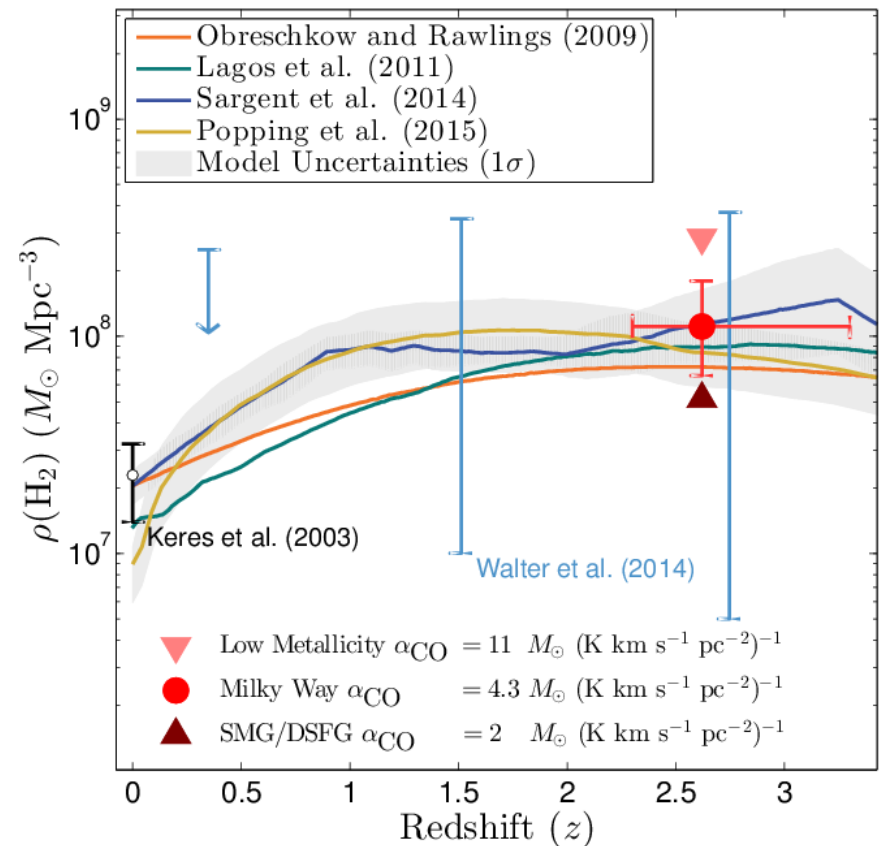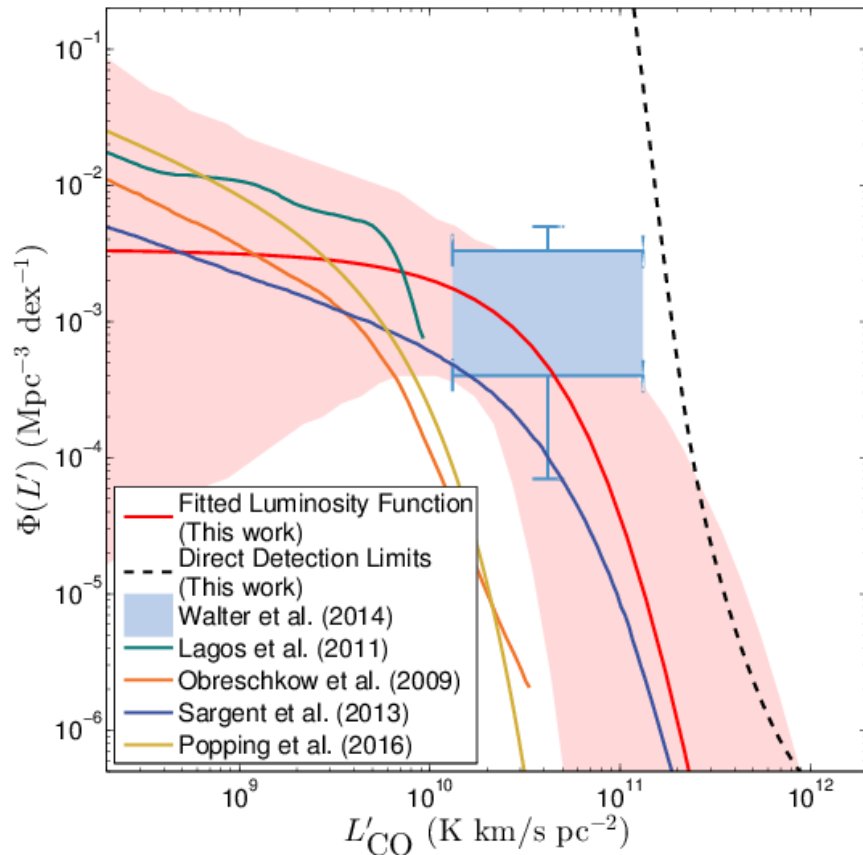
Keating et al., 2016

Light to Halo Mass Constraints

COPSS constraints on A_{CO} appears to rule out three models (Lidz et al. 2011, Model B from Pullen et al. 2013, Visbal & Loeb 2010).

Keating et al., 2016

Cosmic Molecular Gas

Constraints also useful for putting constraints on the "knee" of the CO(1-0) luminosity function. Also capable of constraining cosmic molecular gas abundance at $z \sim 3$ to $\rho(\mathrm{H_2}) = 1.1^{+0.7}_{-0.4} \times 10^8 \; M_\odot \; \mathrm{Mpc}^{-3}$

Keating et al., 2016

The Future…
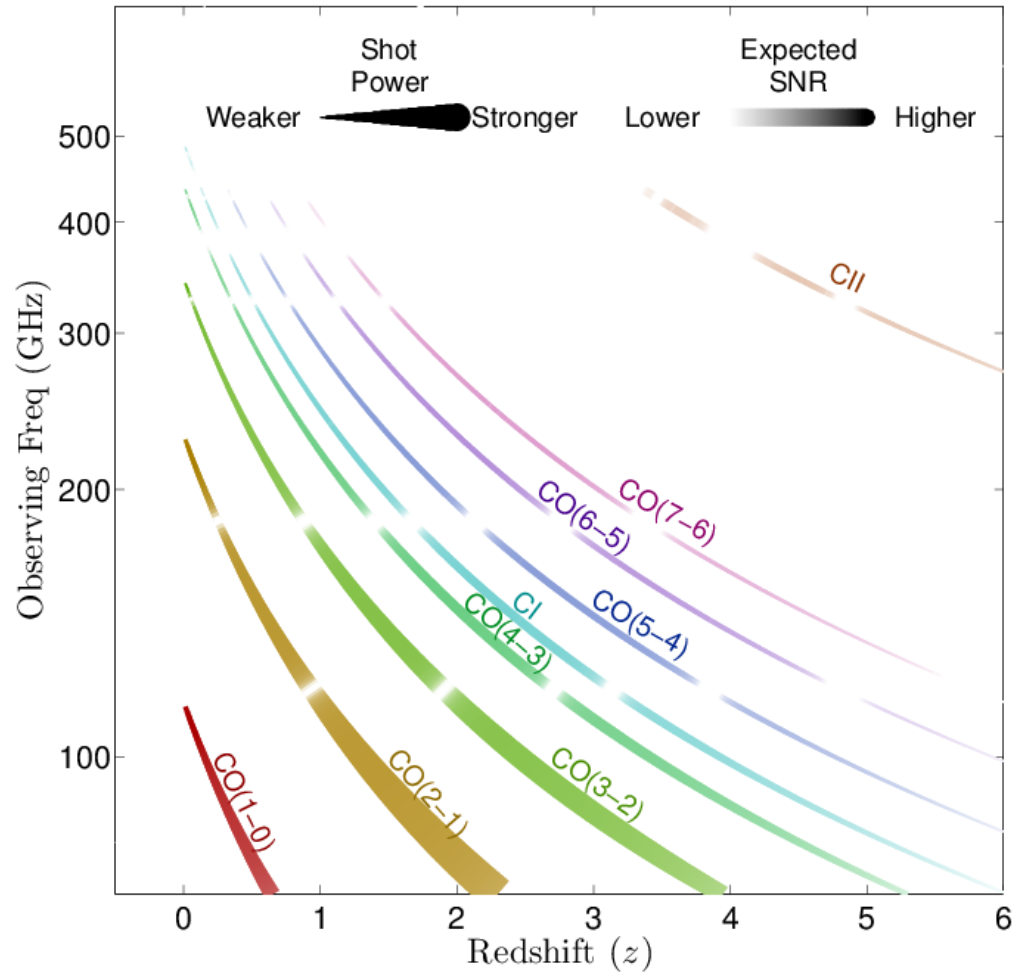

With the results of the COPSS survey, we now have three goals:

- *Confirming our detection/expand our k-coverage at $z \sim 3$*

- *Expanding the redshift coverage of our measurement*

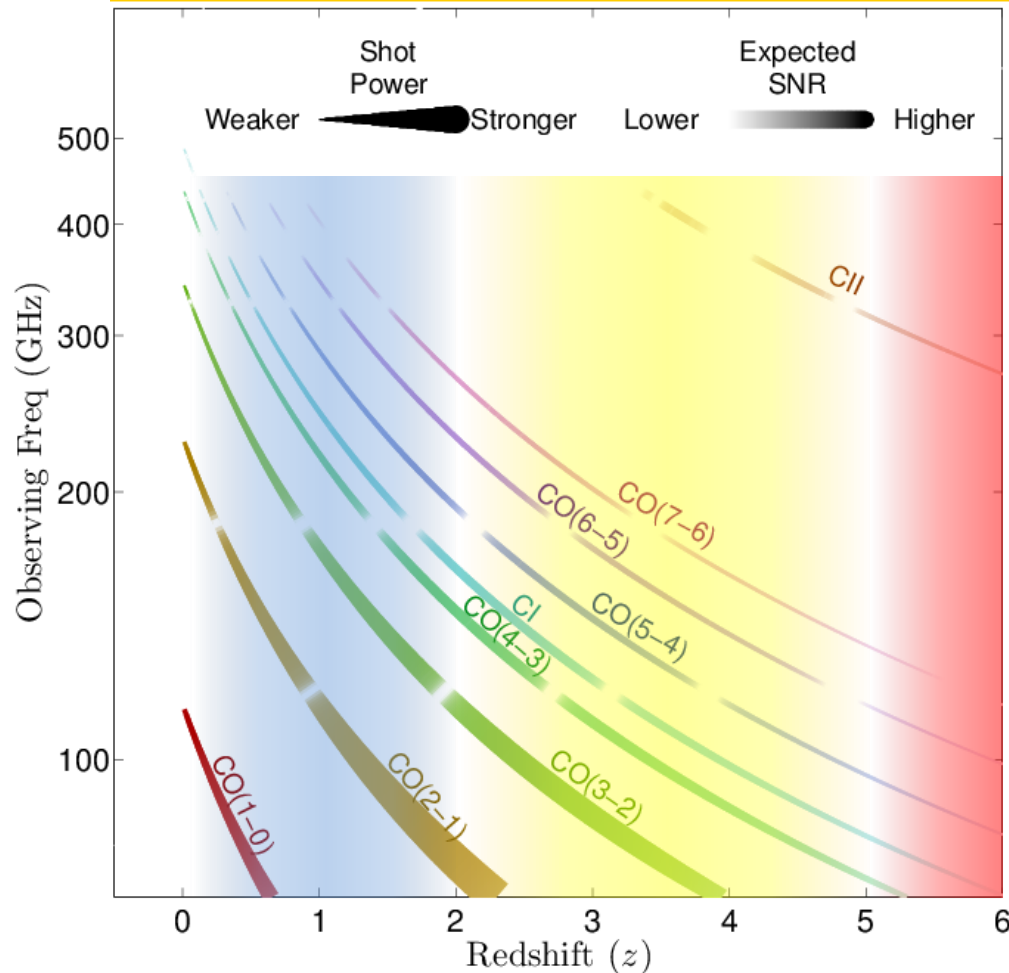- *Looking at tracers other than CO(1-0) for high redshift objects*

Millimeter Intensity Mapping

Millimeter Intensity Mapping

Three science cases of particular (personal) interest:

➤ **Low redshift:**
   Mapping of large-scale structure, BAO

➤ **Moderate redshift:**
   Evolution of ISM/molecular gas in early galaxies

➤ **High redshift:**
   Probe the galaxies in the EoR (Dark Ages?)

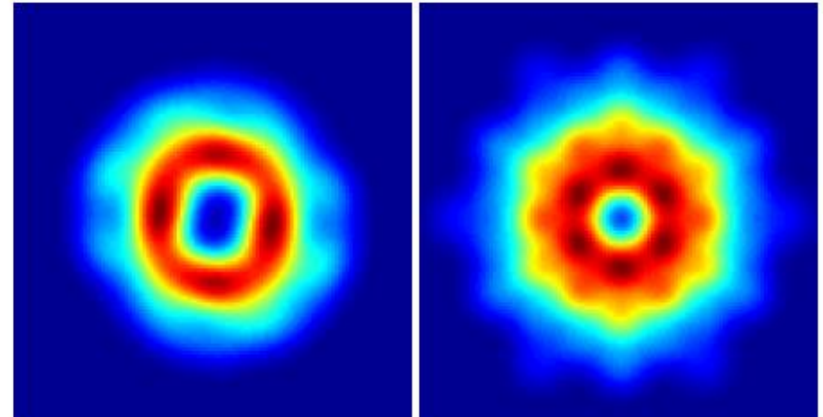To fully explore, we will need to build new instruments:
How can we help motivate this using existing instruments?
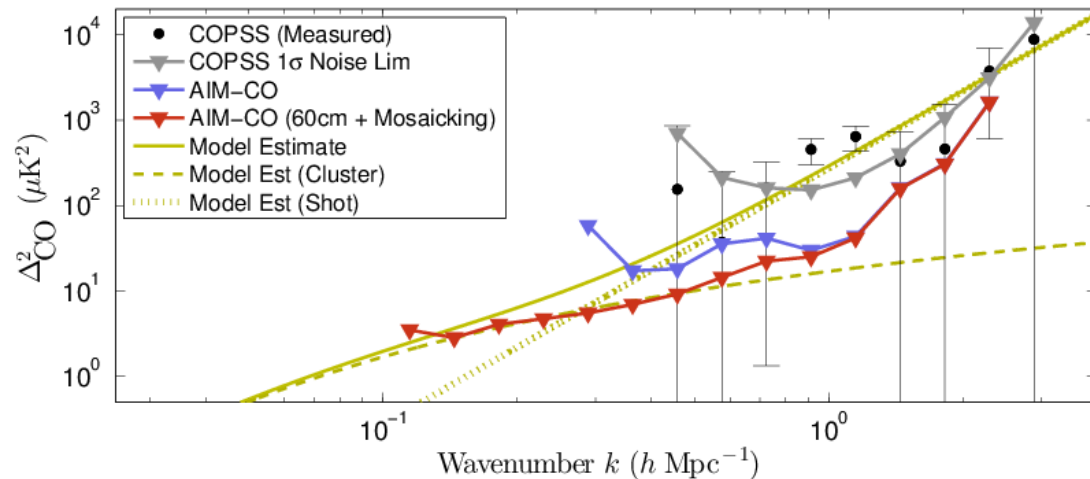
Future CO Intensity Mapping

SZA CO(1-0)   YTLA CO(3-2)

UV Coverage

YTLA observations at 3mm planned to begin within a year, will cover $z \sim 1-2$ using CO(2-1) and $z \sim 2-3$ using CO(3-2).

Legend in plot:
- COPSS (Measured)
- COPSS 1σ Noise Lim
- AIM−CO
- AIM−CO (60cm + Mosaicking)
- Model Estimate
- Model Est (Cluster)
- Model Est (Shot)

Axes:
Δ^2_{CO} (μK^2) vs. Wavenumber k $(h\,\mathrm{Mpc}^{-1})$
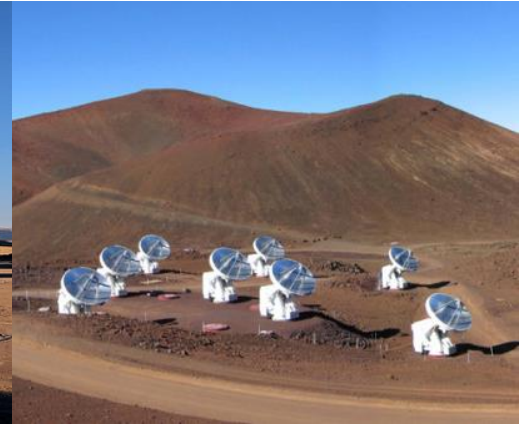
Future CO/[CII] Intensity Mapping

VLA @ 1cm   ACA (ALMA) @ 3mm   SMA @ 1cm

VLA, ACA and SMA have similar primary beam sizes and UV-coverage – **well-suited for cross-correlation!**

For $z \leq 4$: Constrain evolution of CO around the peak of cosmic star formation

For $z \geq 4$: Place constraints on [CII] during the late/post-EoR era of the Universe

Comments and Questions

Concluding points:

- Shot-power measurements can be a powerful tool for providing early constraints of the power spectrum
- Focused on trying to cross early "stepping stones" in order to build towards a focused instrument
- Millimeter-wave intensity mapping is an exciting regime, in part due to the number of lines cross-correlations between

Thank you to the fine folks who made CARMA a world-class facility, and made this research possible!

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